Map Basics: Datums and Coordinate Systems

ESRM 304
Autumn Quarter

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What is a map?

What is a map?

What is the purpose of a map?

How do you know if a map is meeting its intended purpose (or your purpose)?

Early Map of World

The Waldseemüller map, Universalis Cosmographia, is a wall map of the world drawn by German cartographer Martin Waldseemüller originally published in April 1507. It was one of the first maps to chart latitude and longitude precisely, following the example of Ptolemy, and was the first map to use the name "America." Waldseemüller also created globe gores, printed maps designed to be cut out and pasted onto spheres to form globes of the Earth.

Is a map meeting its intended purpose?

- How are features placed on a map?
- How do we trust things that are on a map?
  - How do we know these things are in the right place?

How do we trust things that are on a map?

Control is essential

Careful measurements taken from known locations

How do we know what a "known location" is?

How do you know where you are?

[Discussion]

Hint: how long is a meter?

How do we trust things that are on a map?

Short answer: by agreement (length of a meter)

- 18th Century: 1/10,000,000 of the length from the Equator to the North Pole ("the meridian")
- 1792-1799: expedition measured the length between Dunkerque and Barcelona (1/2 of the meridian)
- 1875: *Bureau International des Poids et Mesures*: the distance between two lines on a standard bar composed of an alloy of 90% Pt and 10% Ir, measured at the melting point of ice
- 1960: 1,650,763.73 wavelengths of the orange-red emission line in the electromagnetic spectrum of ^{86}Kr in a vacuum

Agreement requires standards

Measurement frameworks are the result of agreement and standards

Datums, land division systems, & coordinate systems

Datums (from Wikipedia)

- A geodetic datum (plural datums, not data) is a reference from which measurements are made.
- In surveying and geodesy, a datum is a set of reference points on the earth's surface against which position measurements are made, and
- (often) an associated model of the shape of the earth (reference ellipsoid) to define a geographic coordinate system.

Datums, land division systems, & coordinate systems

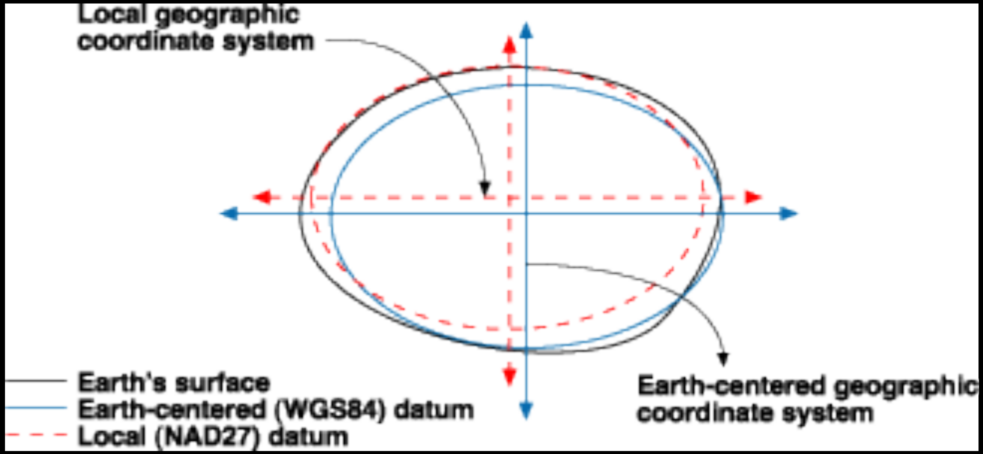
Datums (from Wikipedia)

- Horizontal datums are used for describing a point on the earth's surface, in latitude and longitude or another coordinate system.
- Vertical datums measure elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.

Datums, land division systems, & coordinate systems

Datums

- Is the earth a sphere? No, it is a spheroid/ellipsoid
- The earth is irregularly shaped
- Deformations in the crust (e.g., from gravitational pressure of ice)
- Gravitational forces different where crust thickness varies



Datums, land division systems, & coordinate systems

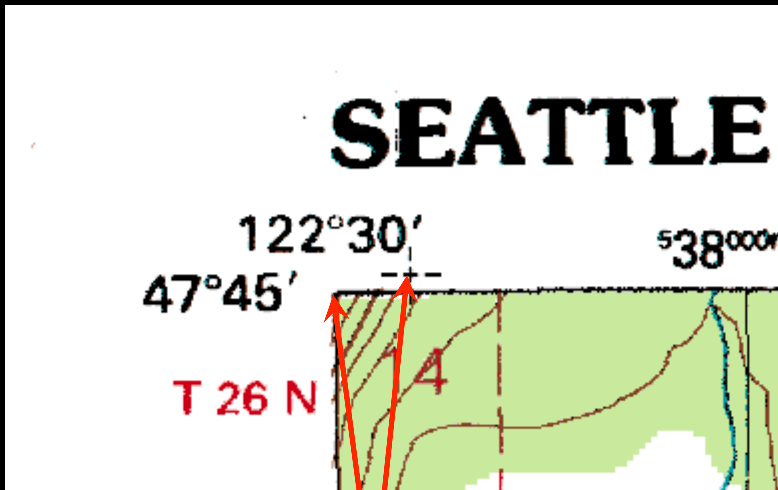
Datums are mathematical models of the shape of the earth created to provide control over the survey measurement framework

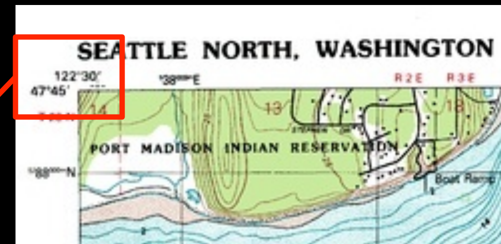
Provide a frame of reference for measuring locations on the earth's surface

Earth-centered datums (e.g., WGS84) provide locational control for the entire planet but do not fit specific locations particularly well

Local datums exist for better local control (e.g., NAD27 or NAD83 for North America)

Datums, land division systems, & coordinate systems





These points represent the same location in two different datums

Projection and 1000-meter grid, zone 10, Universal Transverse Mercator
10,000-foot grid ticks based on Washington coordinate system, north zone
1927 North American Datum
To place on the predicted **North American Datum 1983** move the projection lines
23 meters north and 93 meters east as shown by dashed corner ticks

Datums, land division systems, & coordinate systems

Coordinate systems and land divisions extend the concept of the datum

Establish a (Cartesian) measurement framework

Allow referencing of all features on, above, or below the surface of the earth to each other

Datums, land division systems, & coordinate systems

Examples of different referencing systems

- Metes and bounds
- US Public Land Survey System (PLSS)
- State Plane
- Universal Transverse Mercator (UTM)

Metes and bounds

Based on physical features of local geography, directions, and distances

E.g., "beginning with a corner at the intersection of two stone walls near an apple tree on the north side of Muddy Creek road one mile above the junction of Muddy and Indian Creeks, north for 150 rods to the end of the stone wall bordering the road, then northwest along a line to a large standing rock on the corner of John Smith's place, thence west 150 rods to the corner of a barn near a large oak tree, thence south to Muddy Creek road, thence down the side of the creek road to the starting point."

Metes and bounds

What problems could there be with metes and bounds?

[Discussion]

- Irregular shapes for properties lead to complex descriptions
- The only thing constant is change: trees die, streams move by erosion, properties are sold
- Not useful for large, newly surveyed tracts of land being opened in the west, which were being sold sight unseen to investors

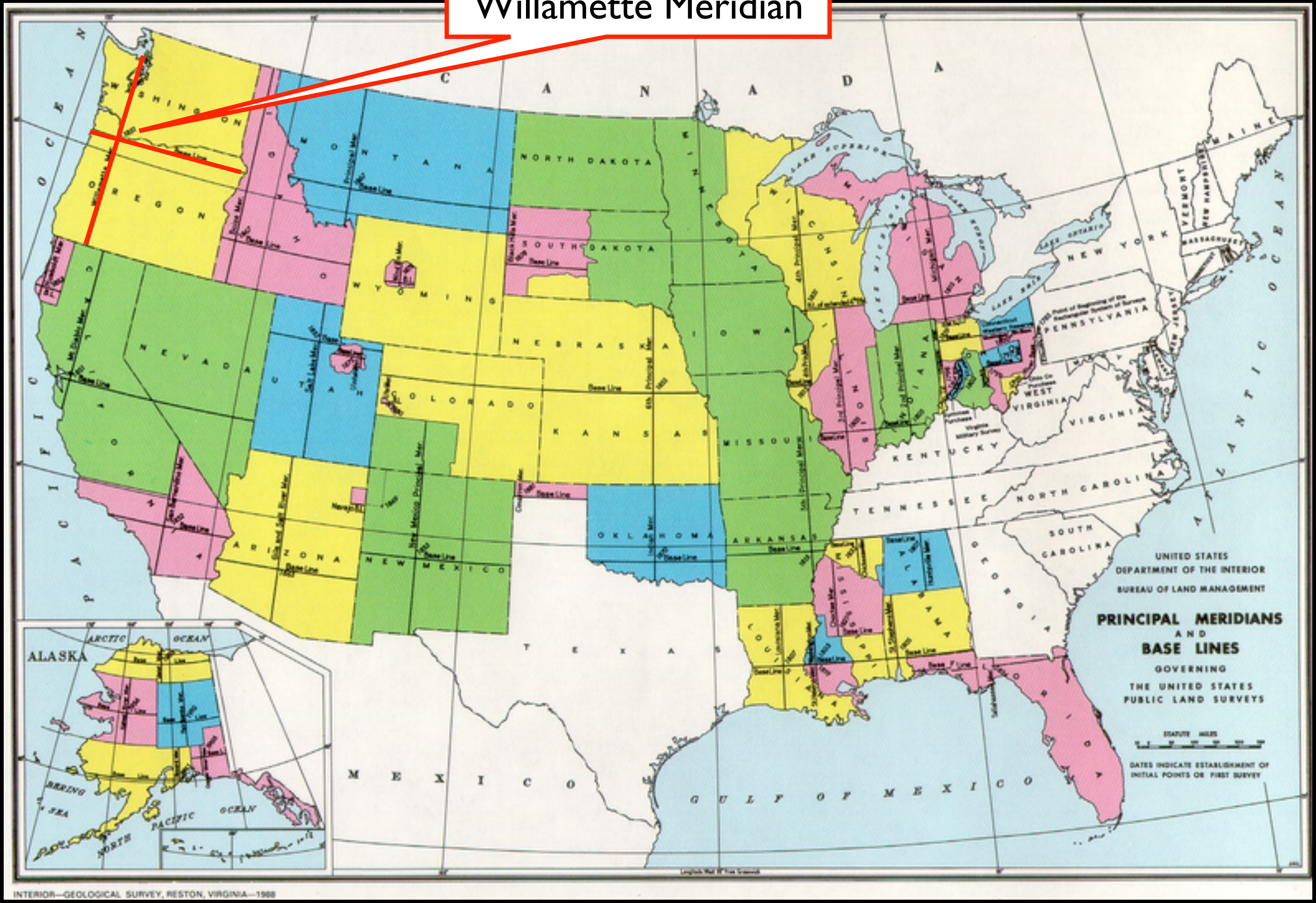
US Public Land Survey System (PLSS)

Established in 1785 (Land Ordinance Survey)

Origin point in E. Ohio

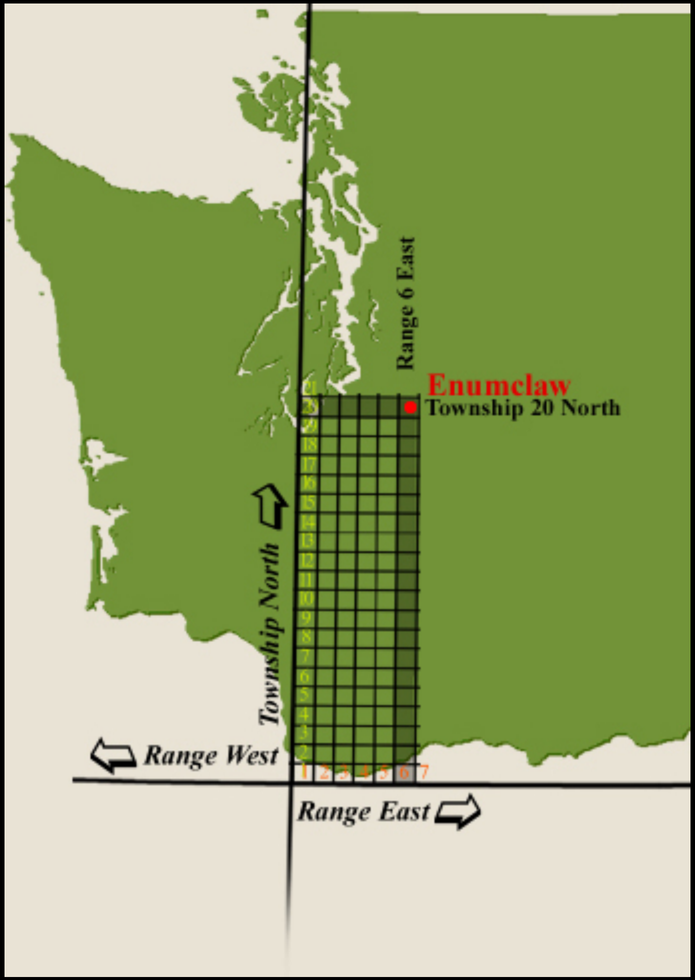
US Public Land Survey System (PLSS)

Willamette Meridian



US Public Land Survey System (PLSS)

Townships and ranges are specified in relation to a meridian



US Public Land Survey System (PLSS)

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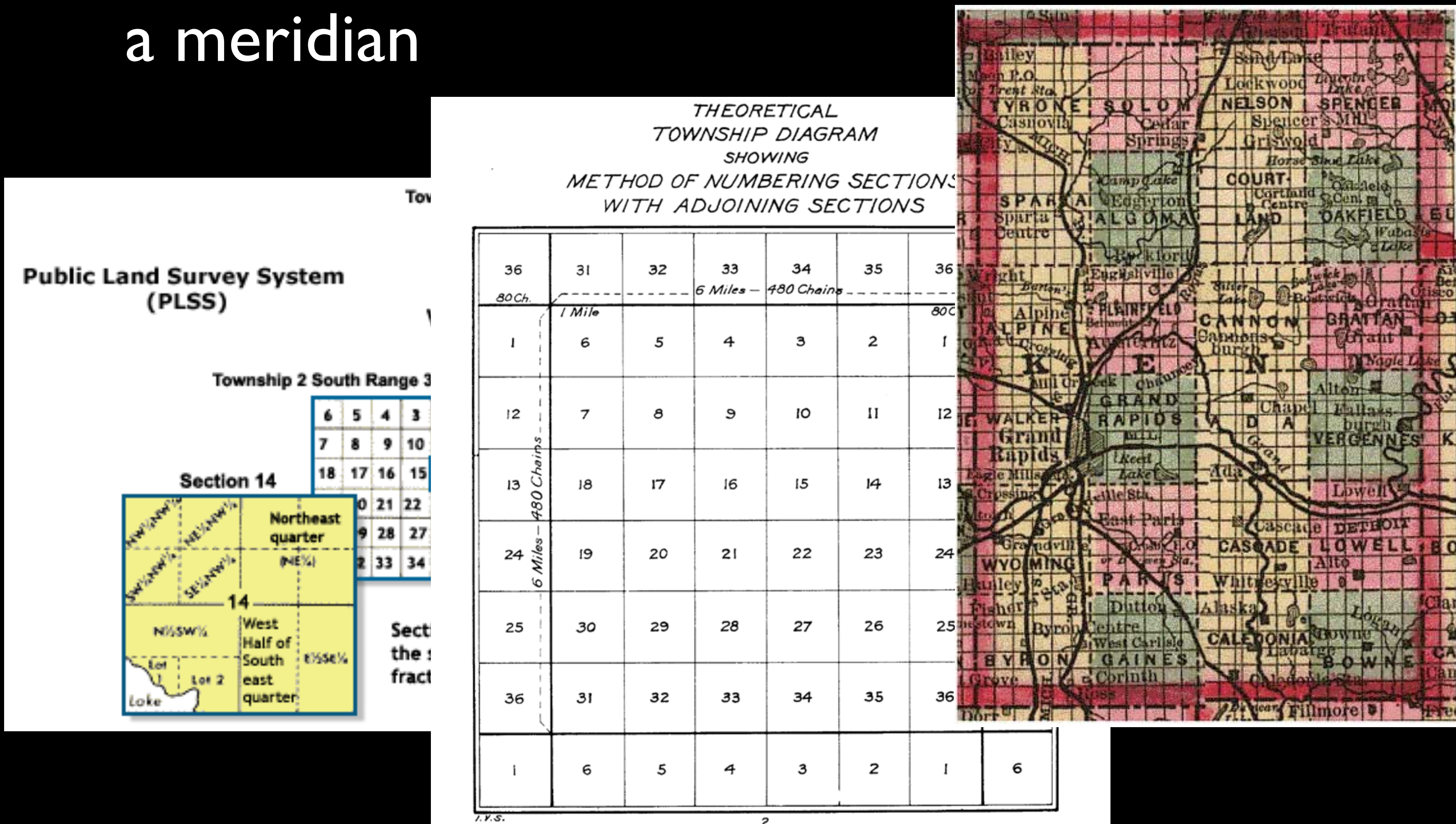
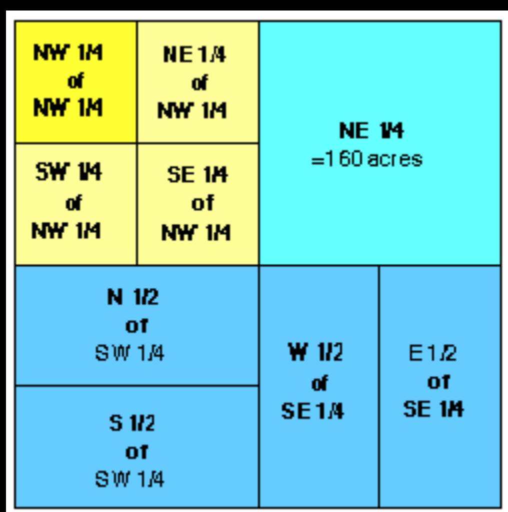


US Public Land Survey System (PLSS)

Townships are subdivided sequentially to refer to specific locations

E.g., "NW ¼ of NW ¼ of section 16 of township 23 N, range 16 E of Willamette Meridian"

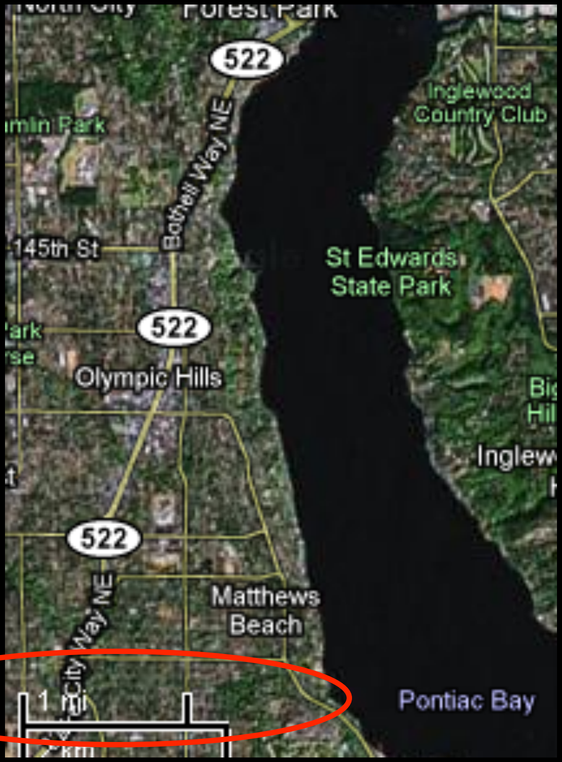


	miles	$mile^2$	acres	m^2	km^2	
Quadrangle	24 by 24	576	368,640		1,492	Usually 16 townships
Township	6 by 6	36	23,040		93	Usually 36 sections
Section		1	640		2.6	
Half-section		1/2	320	1,294,999	1.3	
Quarter-section		1/4	160	647,500		
Half of quarter-section		1/8	80	323,750		
Quarter of quarter-section		1/16	40	161,875		

US Public Land Survey System (PLSS)

The legacy persists:

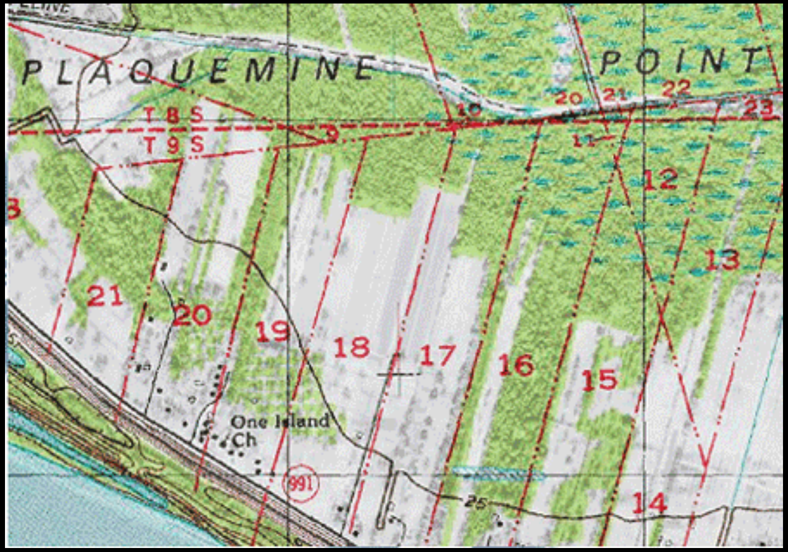
- Each 16th section was originally set aside for support of public schools (in WA, managed by DNR); you should be grateful!
- Land division artifacts



US Public Land Survey System (PLSS)

Problems with PLSS

- Because the earth is an ellipsoid, rectangular divisions will ultimately lead to discrepancies (can you cut an orange peel into squares?)
- Imposition of new system conflicted in some locations with previously existing land divisions



State Plane Coordinate System (SPCS)

- Codified in the 1930s
- Based on a Cartesian coordinate system
- Breaks the US up into a number of zones (124 in US)
- Most states' zones are based on Lambert Conformal Conic or Transverse Mercator projection
- Originally based on NAD27 datum, recently updated to NAD83 with GPS augmentation (HPGN = "High Precision GPS Network)
- Highly accurate (error < 1:10,000 within a zone)

State Plane Coordinate System (SPCS)

Each state or division of state has its own numeric code

- Washington State has 2 zones, based on Lambert Conformal Conic projection
- North zone: 5601
- South zone: 5626

State Plane Coordinate System (SPCS)

Problems with SPCS

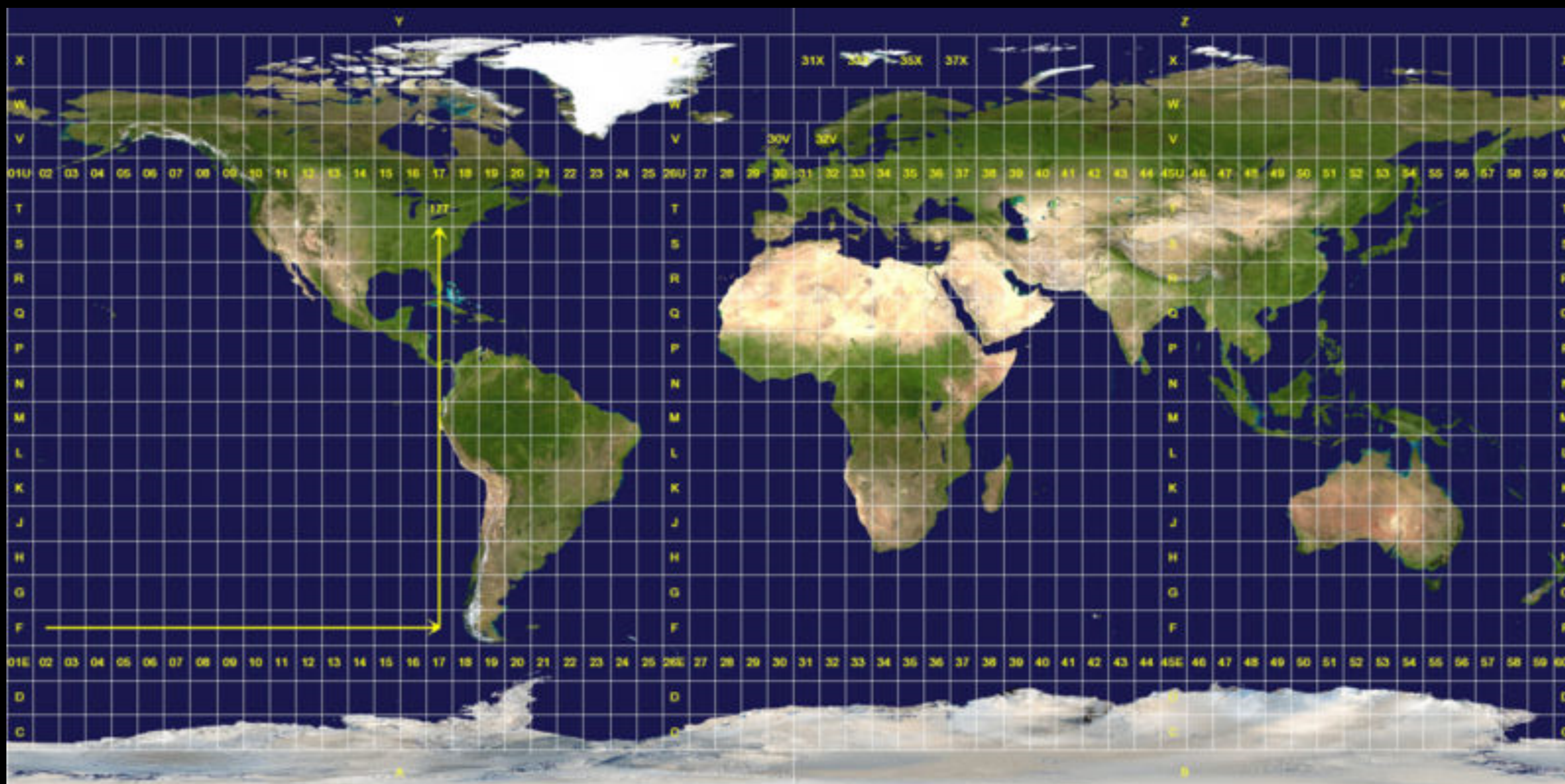
- Each state or state subdivision uses a different zone
  - Makes use of the SPCS in large areas cumbersome
- Accuracy declines outside of a zone
  - Makes use of the SPCS problematic when mapping & analyzing large areas

Universal Transverse Mercator (UTM)

- Developed by US Army Corps of Engineers in 1940s
- A global system (between 80°S latitude and 84°N latitude)
- Unambiguous location for every place on earth
- Based on the Transverse Mercator projection
- 60 zones, each 6° wide

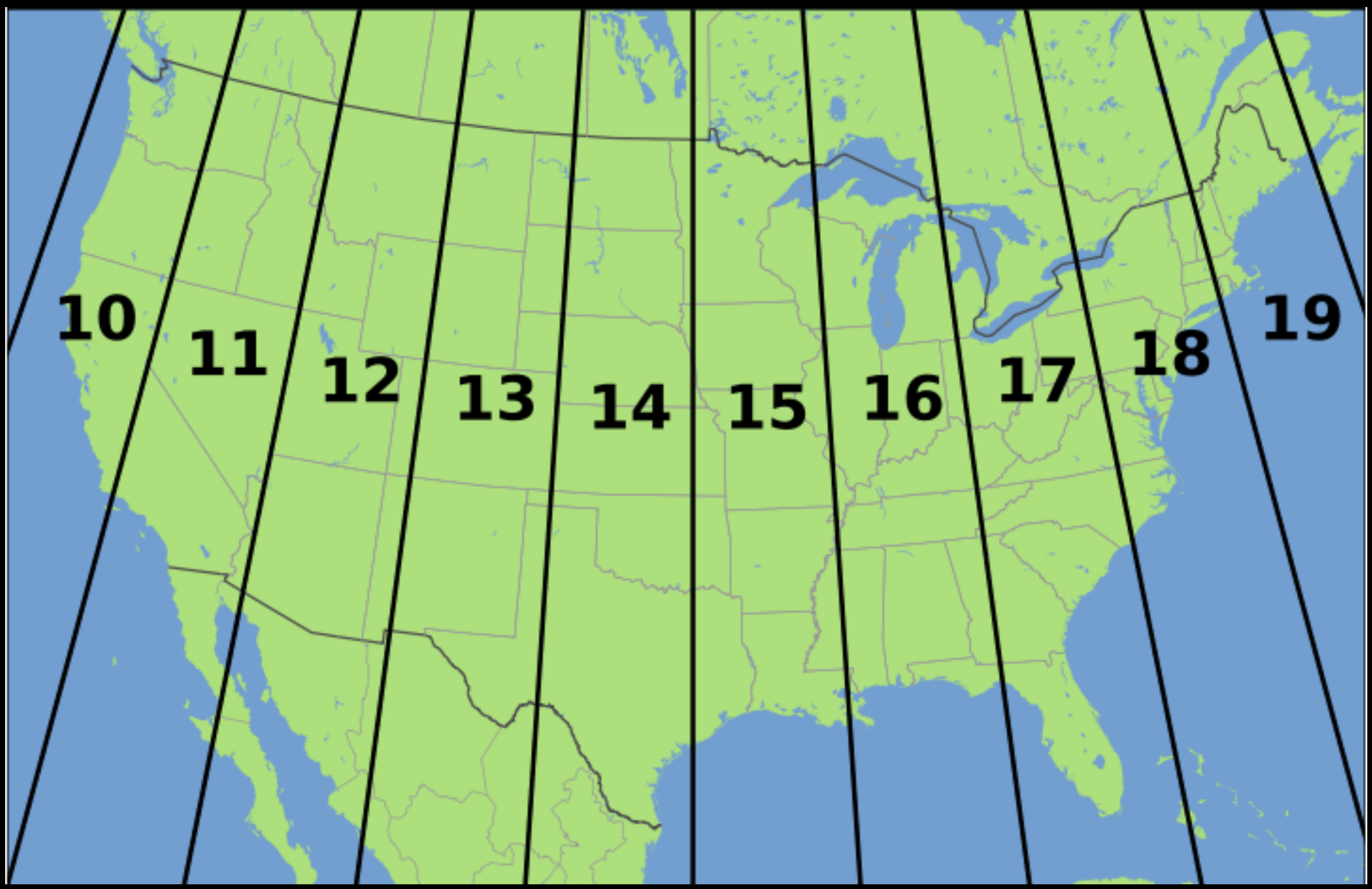
Universal Transverse Mercator (UTM)

Global UTM grid

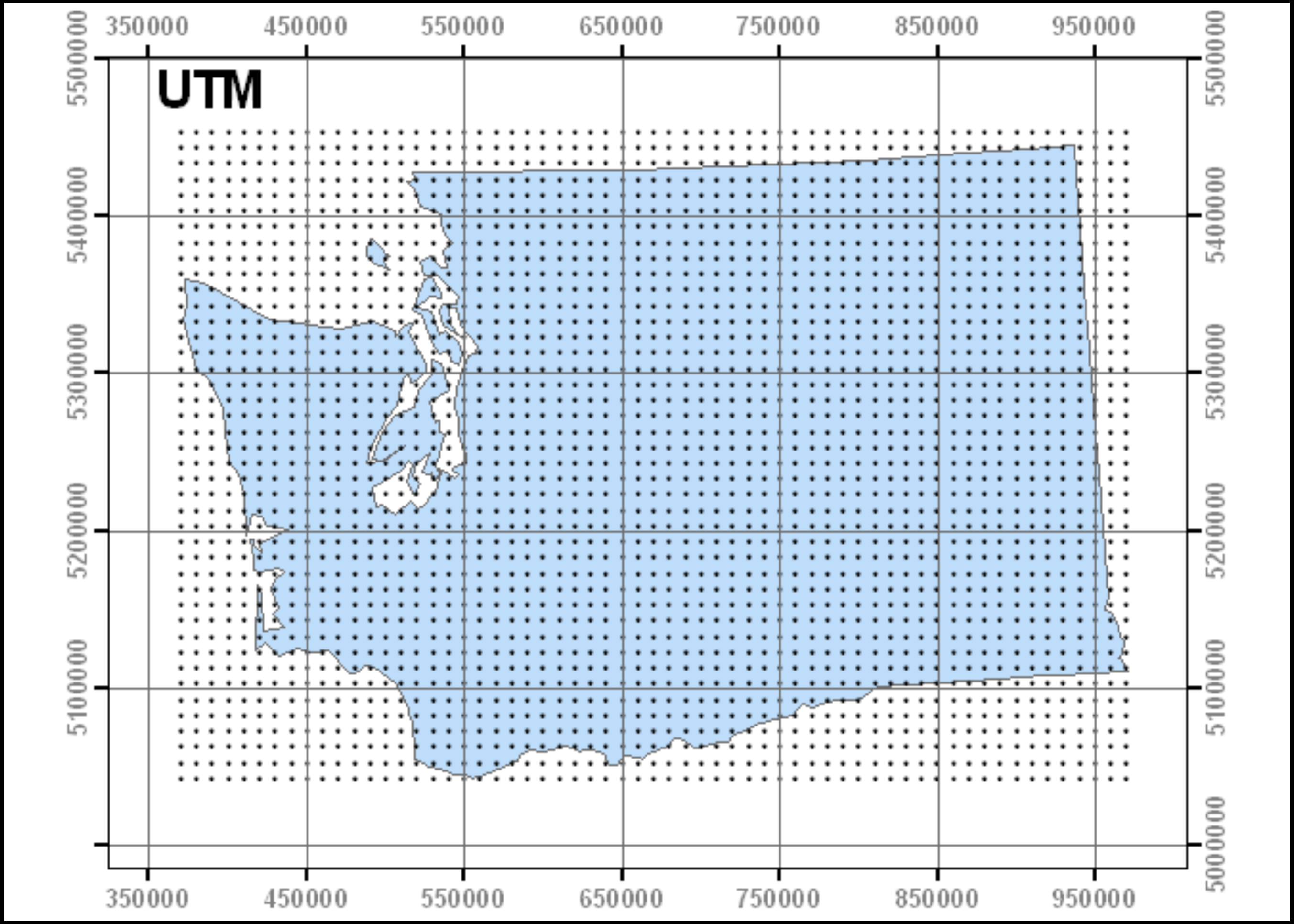


Universal Transverse Mercator (UTM)

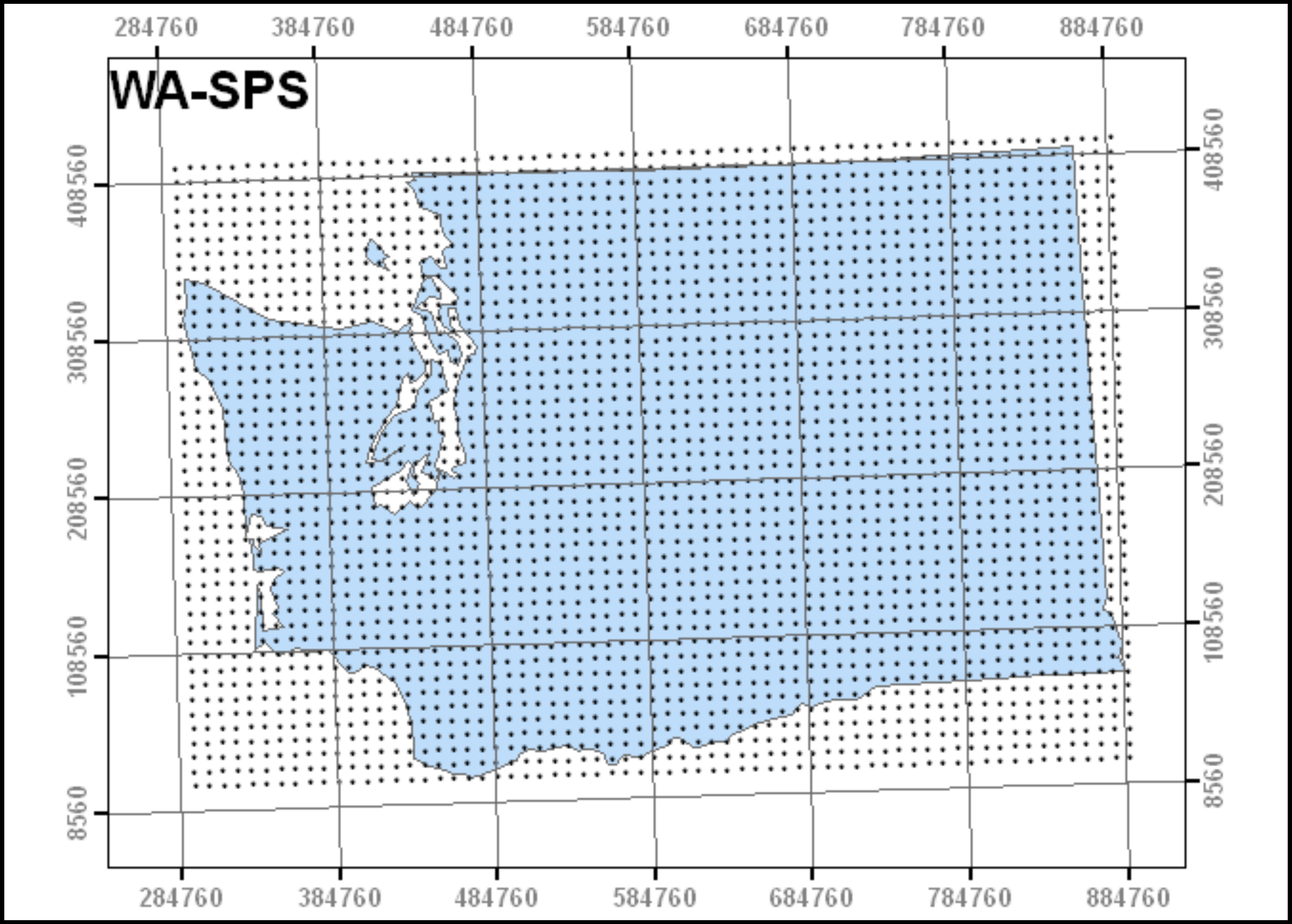
UTM zones in the continental US



Comparing different coordinate systems



Comparing different coordinate systems



Overview of surveying

What is surveying?

"The science and art of making all essential measurements to determine the relative position of points and/or physical and cultural details above, on, or beneath the surface of the Earth, and to depict them in a usable form, or to establish the position of points and/or details."

-American Congress on Surveying and Mapping (ACSM)

Overview of surveying

Why survey?

Surveying allows us to get accurate and valid measurements of things that are on the surface of the earth.

Why would this be important? What would you want to measure?

[Discussion]

Overview of surveying

History of surveying

Overview of surveying

History of surveying (from Wikipedia)

- The **Egyptian** land register (**3000 BC**).
- A recent reassessment of **Stonehenge** (**c.2500 BC**) indicates that the monument was set out by prehistoric surveyors using peg and rope geometry.
- Under the **Romans**, land surveyors were established as a profession, and they established the basic measurements under which the Roman Empire was divided, such as a tax register of conquered lands (**300 AD**).
- The rise of the Caliphate led to extensive surveying throughout the Arab Empire. **Arabic surveyors** invented a variety of specialized instruments for surveying, including:
  - **Instruments for accurate leveling**: A wooden board with a plumb line and two hooks, an equilateral triangle with a plumb line and two hooks, and a reed level.
  - A rotating **alhidade**, used for accurate alignment.
  - A surveying **astrolabe**, used for alignment, measuring angles, triangulation, finding the width of a river, and the distance between two points separated by an impassable obstruction.

Overview of surveying

History of surveying

- In **England**, The Domesday Book by William the Conqueror (**1086**)
  - covered all England
  - contained names of the land owners, area, land quality, and specific information of the area's content and habitants.
  - did not include maps showing exact locations
- **Continental Europe's Cadastre** was created in **1808**
  - founded by Napoleon I (Bonaparte)
  - contained numbers of the parcels of land (or just land), land usage, names etc., and value of the land
  - 100 million parcels of land, triangle survey, measurable survey, map scale: 1:2500 and 1:1250
  - spread fast around Europe, but faced problems especially in Mediterranean countries, Balkan, and Eastern Europe due to cadastre upkeep costs and troubles.

Overview of surveying

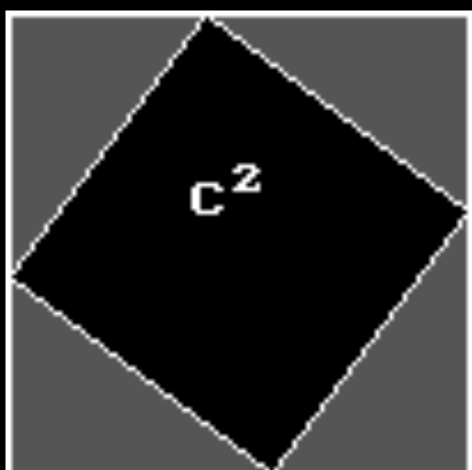
Surveying methods (2 main methods):

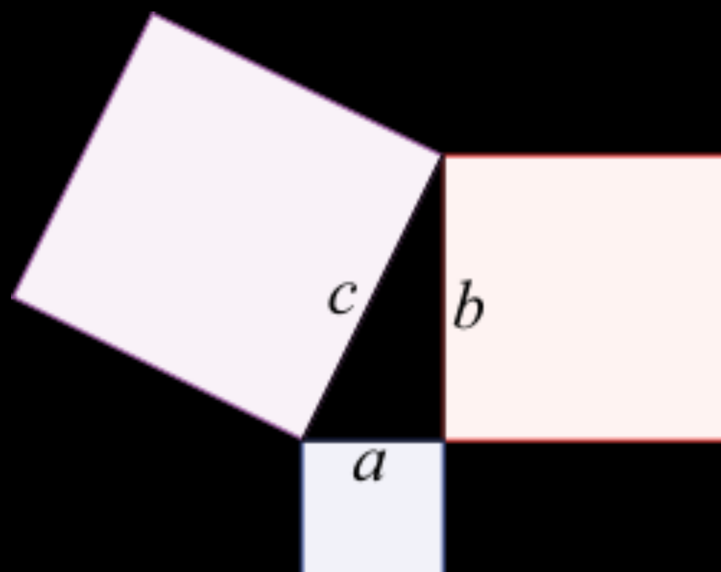
- Geodetic surveying
  - Takes into account the theoretical shape of the earth.
  - Generally high in accuracy, and covering large areas (greater than 300 mi^2).
- Plane surveying
  - Assumes that the survey area is a flat plane.
  - Generally covers small areas (less than 300 mi^2).
  - Most common method used.

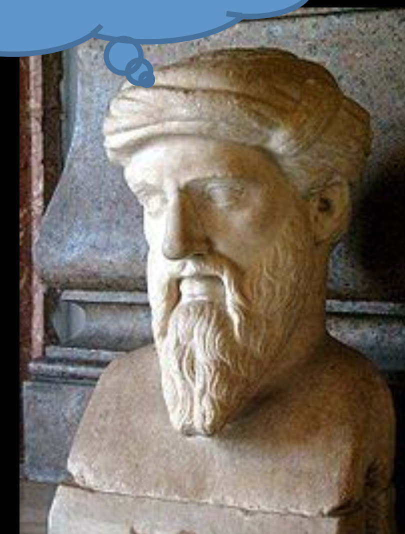
Survey mathematics

It's all about triangles:
Pythagoras knew,
and so should you!

$a^2 + b^2 = c^2$



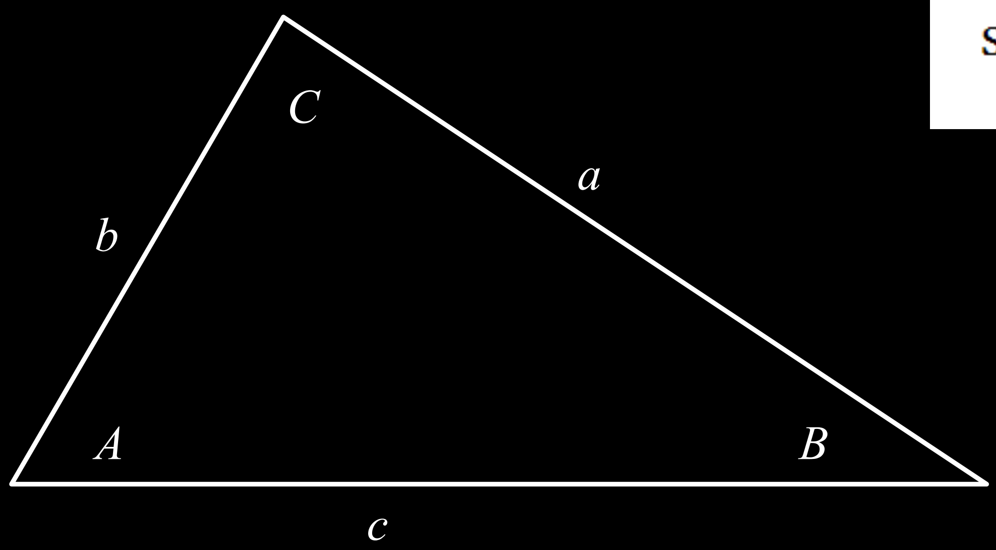




c. 570-c. 495 BC

Survey mathematics

The Law of Sines



$$\frac{a}{\sin(A)} = \frac{b}{\sin(A)} = \frac{c}{\sin(C)}$$

Survey mathematics

The Law of Sines:

- Given:
  - two sides and one angle *or*
  - two angles and one side
- It is possible to get values of all angles and all sides

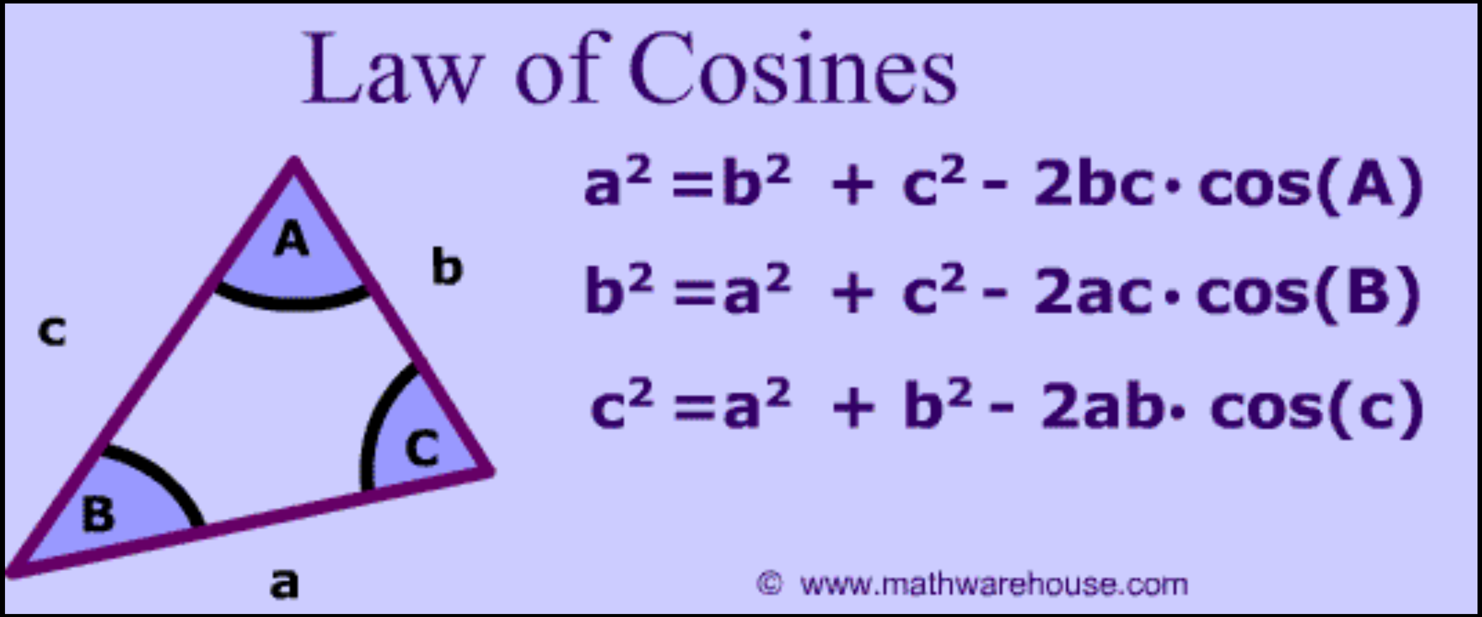
Example: given side a = 20, side c = 24, and angle C = 40°

$$\frac{\sin(A)}{20} = \frac{\sin(40°)}{24} \qquad A = \arcsin\left(\frac{20\sin(40°)}{24}\right) \cong 32.39°$$

Survey mathematics

The Law of Cosines:

- Given:
  - two sides and the enclosed angle
- It is possible to get values of all angles and all sides



Comparing different coordinate systems

Conclusion

- Knowing where things are depends on measurement frameworks
- Measurement frameworks rely on commonly agreed-upon standards
- The great thing about standards is there are so many to choose from
- Calculation of land measurements will vary by measurement framework
- Wherever you go, there you are!